APPENDIX A: Analysis of Ignition Sources

Potential ignition sources were evaluated based on physical evidence, analysis of changes, worker interviews, and historical information. The relative likelihood of each ignition source was judged on a qualitative scale based on factors that either supported or reduced the likelihood. The table below contains the results of the team's analysis.

POTENTIAL IGNITION SOURCE	RELATIVE LIKELIHOOD	SUPPORTING FACTORS	FACTORS THAT REDUCE LIKELIHOOD
Electrical Equipment Arc/Sparking	Low	Booster Room 2 differed from Booster Room 1 in that electrical motors instead of hydraulic systems were used to drive the mixing blades. If the electric systems were not installed properly, grounded, and maintained, then an electrical arc, spark, or fire could supply the stimulus to ignite or detonate the raw materials and the boosters that were present in Booster Room 2. Forklift operations in the booster room could also supply electrical sparks.	Explosion-proof motors, wiring, and lighting had been installed in Booster Room 2. The electrical panels and most of the wiring were located outside of the booster room. The electric motors for the mixing pots were supplied with a positive airflow around the motor housings which reduced the risk of dust and explosive material buildup near the motor windings.
Static Electricity	Low	The booster room floor had been painted with a non-conductive epoxy paint that would prevent the dissipation of static-charge buildup. The bristles of the brooms, used to sweep the floor area, were made of synthetic fibers that through friction with the floor could generate a static charge. The booster room also contained plastic buckets and dust pans that could form a static charge through friction with worker clothing and other materials. The workers frequently wore their own personal clothing under the company-supplied cotton coveralls. Friction between personal clothing with a high synthetic fiber content and the	Cleaning operations, which could be a source of static charge, would not be expected in Booster Room 2 at the time (7:54 AM) of the incident. *DoD Contractors' Safety Manual for Ammunition and Explosives* states "Humidification for preventing static electricity accumulations and subsequent discharges is usually effective if the relative humidity is above 60 percent." The relative humidity, reported by the weather service that morning, was over 80 percent in Reno. It was reported that PETN with a higher moisture content was brought to

POTENTIAL IGNITION SOURCE	RELATIVE LIKELIHOOD	SUPPORTING FACTORS	FACTORS THAT REDUCE LIKELIHOOD
Static Electricity (continued)		cotton overalls could supply an ideal condition for formation of a static charge. Because of the cold outdoor temperature on the day of the incident, the workers wore their regular clothing under their coveralls. The pouring of dry explosives, especially PETN, and airflow friction from the ventilation system could generate hazardous levels of static electricity. During the interviews of Sierra employees, operators reported that static-charge buildup occurred during raw-material handling in the booster room. The problem appears to have been particularly severe while pouring dried PETN. At the time of the explosions, the pots could be at their operating temperature of 85°C, and although the relative humidity reported by the weather service was over 80 percent, the relative humidity near the operating areas of the pots could be well below 60 percent.	Booster Room 2 due to the higher heat capacity of the steam-heated mixing pots. The electric discharge energy required to detonate PETN increases with increasing water content. Cold ambient temperatures also increase the ignition energy required.
Mechanical Spark Caused by Nails When Pallet is Dragged Across Concrete	Low	Mechanically generated sparks could ignite dust and explosive raw material on the booster-room floor.	The raw explosive materials already had been staged in Booster Room 2 the previous day. The forklift was not in use. Ignition of dust on the booster-room floor is not likely to transition from deflagration to detonation.
Ferrous Metal Objects Impact, Generating a Spark	Moderate	The Comp-B that was used as a raw material sometimes contained foreign material. If the foreign object was composed of a ferrous material and was impacted by a hammer blow or mixer-blade, then a spark could have resulted and ignited the raw material.	Some employees visually inspect the Comp-B as it is opened.
Friction and Static when Dry PETN is Mixed	Moderate	PETN was sometimes added to the Pentolite mixing pot before molten TNT was present to remove any residual moisture. The presence of dry PETN increased the ignition sensitivity.	

POTENTIAL IGNITION SOURCE	RELATIVE LIKELIHOOD	SUPPORTING FACTORS	FACTORS THAT REDUCE LIKELIHOOD
Friction when Pallet Slides Over Explosives on Floor	Improbable	Such mechanical action could supply sufficient energy for ignition.	The interviewed workers were aware of the potential dangers of bulk explosives or excessive manufacturing residue and waste on the pour-room floor. Good housekeeping practices were emphasized. Raw materials already had been staged in the booster rooms so no movement of pallets would be expected.
Forklift Strikes Explosives	Improbable	A forklift impact on containers of the raw material or the finished product could supply enough energy by spark, friction, or impact to trigger an ignition and/or detonation of the contacted material.	The forklift was located in the warehouse, and workers who might use it had not started work.
Striking Explosives with Metal Tools	Moderate	It was common practice to break up rejected boosters of Comp-B with both plastic and steel hammers. A review of U.S. Army incident summaries indicates that numerous past incidents were caused by the impact of hand tools on explosives containing TNT and RDX.	Only two boxes of rejected boosters had accumulated in Booster Room 2 since it went into operation. Rejected boosters were to be taken from Booster Room 2 to Booster Room 1 to be broken up and recycled. The explosion occurred in Booster Room 2.
Mixing Blade Impacts Hardened Explosives	High	If residual solid-base mix or Pentolite remained in the pot and the melt-pot mixing blade was engaged, impact forces on the explosives could ignite a large quantity (~50lbs.) of the base mix or Pentolite. Reportedly, about 50-100 lbs. of base mix had been left in pot 5 the preceding night. The crossover of personnel and melting techniques from the evening shift to the day shift increased the chance of operators not taking the proper sequence of steps to ensure a melt had formed before engaging the mixing blades. Because the operator in Booster Room 2 had previously worked on the second shift in Booster Room 1, he never had to inspect the pot in Booster Room 1 before turning on the mixer. An inspection of the pot was not needed in Booster Room 1	When asked, operators recognized that the pots should be inspected at the beginning of a shift to ensure that no solid material was present in the pot. Most operators, however, did not include this step in describing the melt/pour process. No startup checklist existed and a record to ensure that the inspection occurred was not maintained.

POTENTIAL IGNITION SOURCE	RELATIVE LIKELIHOOD	SUPPORTING FACTORS	FACTORS THAT REDUCE LIKELIHOOD
Mixing Blade Impacts Hardened Explosives (continued)		because the heat would have been left on and the material still would have been melted from the previous shift. Because the two operators in Booster Room 2 had talked about the leftover base mix, the operator who left it may have assumed the other operator had used it.	
Tool or Pot Component Drops into the Pot	Low	Workers indicated that at times large pieces of Comp-B were broken up with hammers on top of, or even on the edge of, the opening into which the raw explosive materials were poured into the pot.	A component entering one of the large mixing pots is unlikely. The large mixing pots have no internal removable parts, and the penetrations through the lid around the shaft and breaker bars do not permit materials to enter the pot. Because of the heating capacity of the pots in Booster Room 2, there was less need to break down Comp-B clumps.
Foreign Object in the Explosives Struck by Mixing Blade	Low	Foreign materials were frequently found in the Comp-B. Comp-B and substitute materials were recovered from DoD munitions and would be expected to have foreign materials present from the demilitarization operations. Only cursory visual inspections of the Comp-B were used to eliminate foreign materials. The Comp-B was never screened on site to remove foreign objects. If a foreign object were to jam between the mixing blade and the pot wall, drag friction and pinching could readily provide the energy necessary to ignite or detonate the base mix.	There was an approximately one-inch clearance between the mixing blade and the tank wall. Any foreign objects that might strike the mixing blade and pot wall would need a size greater than about one inch. The tanks in Booster Room 2 were designed with a drain line that provided additional clearance below the mixing blade in the base of the pot. The mixing blade turned at a relatively low rotation rate, so the impact velocity on a foreign object present in the mix would be minimal.
Open Flame due to Lighters/Smoking	Low	Workers were not prohibited from bringing smoking materials into the change room in their regular clothes. Cigarettes and a lighter were found in a coat located in the debris near the change room.	The operator who was working in Booster Room 2 smoked little, if at all, and workers knew that they were only to smoke in the break room and could be fired if they were caught smoking anywhere else.
Chemical Reaction Between Explosive Types	Improbable	The Comp-B used to produce the boosters is demilitarized material. The explosive is purchased through a bid process delivered in bulk quantity “as is.”	Explosives, including HMX, LX-14, Comp A-3, and Comp-H-6, had been melted and blended before without evidence of chemical reaction. An immediate

POTENTIAL IGNITION SOURCE	RELATIVE LIKELIHOOD	SUPPORTING FACTORS	FACTORS THAT REDUCE LIKELIHOOD
		Examination of the Comp-B currently in Sierra's inventory showed that, besides the material labeled as Comp-B, other military explosive compositions were included. Other demilitarized explosives present in the storage magazine included HMX, LX-14, Comp A-3, and Comp H-6. These explosive formulations were found in the same storage area of the magazine and often were observed on the same pallets as the Comp-B. All explosives were packaged in similar brown cardboard boxes that differed only in the attachment of a small label identifying the contents. The operators were not trained to recognize the difference in properties of the non-Comp-B explosives. Instead, they treated the non-Comp B explosives like Comp-B and added the other explosive formulations to the base mix as if the other compositions were actually Comp-B. Operators relied on process experience to limit the amount of some material, like HMX, that they would add to the mix because they observed that the material would not melt. Sierra did not test the explosives for chemical purity, nor was the material subjected to physical sensitivity tests, such as differential thermal analysis. The actual chemical purity and the behavior of different batches of raw material when heated was therefore unknown. Chemical incompatibility and the possibility of violent chemical reaction among the different explosive compositions cannot be ruled out, especially given the manufacturing process of heating, melting, and blending.	and violent chemical reaction without some early indication of reaction, like the emission of NOx vapors, is not considered a credible failure mode.

POTENTIAL IGNITION SOURCE	RELATIVE LIKELIHOOD	SUPPORTING FACTORS	FACTORS THAT REDUCE LIKELIHOOD
Cross-Contamination Between Processes	Improbable	Other chemicals, incompatible with explosives, were handled in a room adjacent to Booster Room 2. The chemicals were used to manufacture flux. Explosive materials on the pouring tables and surrounding floor were swept up and added to a subsequent batch of base mix in a mixing pot. One forklift serviced both booster-production and flux-manufacturing areas.	The floor of the adjacent building in which the flux operations were conducted was about six inches below the level of the floor in Booster Room 2. Any contamination from floor sweepings would need to be elevated to the booster room. The raw materials for the flux operations were stored separately from the raw materials for the booster fabrication. Workers trained in booster fabrication and flux-composition manufacture did not enter each other's work areas. The operations of melting and pouring the explosive compositions would have the effect of self-cleaning the pots, which would minimize the effects of cross-contamination even if present. Periodic steam cleaning of the booster rooms would remove chemical contamination.
Mechanical Failure of Bearings	Improbable	Enough energy could be generated by a bearing failure to generate heat and sparks, thus igniting nearby combustible material.	The transmission and bearings were located inside a casing outside the pot in which the explosives were being mixed. The transmission was new, and the bearings reportedly were being greased periodically. A bearing failure would be unlikely at or shortly after startup and would not contact the explosives.
Propane Leak and Fire	Improbable	Ignition of leaking propane in the booster room could cause detonation of explosive raw materials. Propane was used to fire the steam boiler.	Leaking propane is easy to detect due to the addition of an odorizer. There were workers who walked close to the boiler room as they came to work, and there were workers working in the vicinity. Ignition of a buildup of propane in the boiler room would be unlikely to impact explosives in the booster room, which was separated by distance and two concrete-filled block walls. A propane fire by itself would give nearby workers a chance to respond. There was no indication of such a response.

POTENTIAL IGNITION SOURCE	RELATIVE LIKELIHOOD	SUPPORTING FACTORS	FACTORS THAT REDUCE LIKELIHOOD
Steam Boiler Explosion	Improbable	The steam boiler had not received a final inspection.	The boiler was a low-pressure boiler with pressure relief at 15psi. Inspection of the boiler following the explosion showed no signs of an internal explosion.
Sabotage	Improbable	A variety of means could be used intentionally to detonate explosives.	The Sheriff and BATF investigation found no evidence of a criminal nature or of an intentional act.